ABSTRACT OR SUPPORTING INFORMATION

CONDUIT—Control Designer's Unified Interface

By

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CONDUIT, which stands for control designer's unified interface, is a computer software package. Its purpose is to assist a human control system designer in designing control systems for aircraft. At the present time CONDUIT is being used by most of the major U. S. rotorcraft and fixed-wing aircraft manufacturers to assist in the design of stability and control augmentation systems. Work is also continuing on the development of additional features for CONDUIT, including tools for analyzing the sensitivity of solutions, and on further enhancements to the basic package. The purpose of this paper is to describe CONDUIT, its operation, and the sensitivity tools that are being developed for inclusion in the next release of the package.

CONDUIT is a descendant of work on computer-aided design done by Polak, Sangiovanni-Vincentelli, and their students [1]. Their idea was to formulate design problems as multi-criterion parametric optimization problems. Their rationale for this was firstly that real design problems usually involve multiple constraints nd multiple performance criteria and secondly that algorithms could be developed to iteratively solve such problems on a computer. They further argued that this would provide a natural division of labor between a human designer, who would select the structure of the design, and a computer, which would then optimize the parameters of the design.

In fact, the human designer would have to continually monitor the computer's progress and make adjustments to the problem formulation that would guide the computer to a good solution. The primary reason for this is that the computer needs to work on a problem involving only a single objective at any given instant. It is therefore necessary to combine the multiple performance criteria into a single performance criterion. Any such single objective would depend on the relative weights assigned to the original performance measures and the relative scaling of the original constraints and objective functions. Because the scaling could not be fully known a priori, the human designer would have to readjust the relative weights after each iteration.

Several computer packages to implement this collection of ideas have been developed. These include DELIGHT [2], ANDECS [3], and CONSOL-OPTCAD [4]. The first step in the development of CONDUIT was a feasibility study of the use of CONSOL-OPTCAD for the design of a stability and control augmentation system (SCAS) for the UH-60A Rascal rotorcraft [5]. The rationale for the study was that the design of a SCAS fits very well into the design framework described above. There is a large set of specifications. The different aircraft companies have different controller structures that they prefer to use. The controllers have many design parameters that need to be at least tuned and preferably optimized.

The feasibility study was a success [5]. Relatively inexperienced control system designers were able to produce a satisfactory design in a reasonably short time. Thus, CONSOL-OPTCAD was shown to enhance the productivity of SCAS designers. One negative aspect did emerge from the feasibility study. The user of CONSOL-OPTCAD for SCAS design needed to be an expert computer programmer, an expert in ptimization, and an expert in control system design. One individual possessing all of this expertise would be re. The developers of CONSOL-OPTCAD had assumed that an expert in optimization would set up the problem with the aid of a programmer and then a designer would interact with the computer to solve the problem.

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We believe a better approach is to minimize the computer programming needed to set up a design problem and to minimize the optimization expertise needed to set up and solve a problem. By doing this, a control system designer can set up and run his problem without help. Of course, it is only possible to do this in relatively narrow design domains, such as aircraft control systems.

CONDUIT is our implementation of this idea. At its heart, CONDUIT includes CONSOL-OPTCAD as the optimization engine. Setting up a problem in CONSOL-OPTCAD requires creation of three items, a computer simulation of the system including its controller, a list of design parameters, and a collection of constraints and objectives (specifications) in a form suitable for computer evaluation. CONDUIT requires the simulation to be done in Simulink®. Because Simulink is a block diagram based simulation language it is intuitive and easy for aircraft control system designers to use. The list of design parameters is a MATLAB® file. CONDUIT comes with a large collection of aircraft control system specifications already programmed. This collection includes essentially all the Mil Spec handling qualities for piloted aircraft [6,7], both fixed and rotary wing. It also includes many classical servomechanism specifications. The CONDUIT user can import any of these specs into his problem by simply dragging them from the spec library to the Handling Qualities Window that is automatically associated with his problem. Connecting the specs to the simulation is accomplished by means of a menu-driven interface. Thus, setting up an aircraft control-system-design problem in CONDUIT requires essentially no programming and no knowledge of optimization.

A more sophisticated designer, or one with unusual specifications, can create his own specs using a menu-driven interface we call Specmaker. Using Specmaker does not require any programming. It is somewhat more complicated than using the specs that already exist within CONDUIT. Once a new spec is created, we encourage designers to share it with other users by adding it to the CONDUIT web site.

Running a problem in CONDUIT, as well as entering the set up mode, is accomplished by pointing and clicking on a menu. Displaying the current value of any spec, the current values of the design parameters, and the supporting data for the evaluation of the specs is also accomplished by pointing and clicking on a menu. At present, we believe the designer still needs some expertise in optimization to interact most effectively with CONDUIT as it iterates towards a solution to a design problem. However, aircraft control system designers are using it effectively, successfully, and happily.

Our current work on CONDUIT can be divided into two parts, enhancements to the package and research on aircraft control system design. The major enhancement currently underway is to add additional block diagram based simulation languages to CONDUIT so users will have some choice of simulation language. The first of these will be Xmath from ISI. A second enhancement is planned. It is based on current research into the sensitivity of the specifications to the design parameters. This will be outlined in more detail below.

Our current research can be divided into two areas. Research is being performed on aircraft control system design using CONDUIT. There are a number of such projects but their results will be reported elsewhere. The second area of research is the previously mentioned work on sensitivity. Our main purpose is to provide tools to help the designer interact effectively with CONDUIT in solving control design problems. One could say that the goal is to replace the optimization expertise needed to run CONDUIT by a set of tools. In order to achieve this goal it is first necessary to understand the local behavior of the CONSOL-OPTCAD algorithms as well as the local dependence of the specifications on the design parameters. These are classically understood as sensitivity problems.

We have thus far developed a collection of sensitivity metrics that are analogous to those used in maximum likelihood estimation [8]. Details and examples will be given in the actual paper. Briefly, because the problems CONDUIT is solving are effectively constrained optimization problems the gradients of the objectives and constraints are almost never zero–even at an optimum. Furthermore, the accuracy of the data is insufficient to support reliable calculations of the true Hessian matrices associated with individual specifications. Thus, the useful sensitivity information is contained in the gradients. The important features are the angles between the gradient vectors and their relative lengths. We have developed ways to display this information for CONDUIT users, rules of thumb for evaluating this information and guidelines for using it to "drive" CONDUIT. These will be described in detail in the paper along with examples of their use.

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